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Inspection of the Large Optics Diamond Turning Machine

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Inspection of the Large Optics

Diamond Turning Machine*

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The Large Optics Diamond Turning Machine (LODTM) is a vertical spindle axis lathe which was constructed in response to the need to fabricate high accuracy reflectors for laser applications. The LODTM is capable of swinging a 64 inch diameter workpiece weighing up to 3,000 pounds. The design specifications called for the machine to produce a finished workpiece with a surface figure error approximately bounded by 1 microinch rms. The design of the LODTM is shown in figure 1; figure 2 shows the work zone with a small workpiece in place.

The LODTM is of stacked slide design, somewhat resembling a bridge type coordinate measuring machine. In fact, the machine must serve as a measuring machine for the quality control steps of workpiece manufacture since there is not currently another method of measuring the highly aspheric parts manufactured. To calibrate the LODTM and provide an independent check of its accuracy as a measuring machine, a joint effort was mounted with a team from the National Bureau of Standards at Gaithersburg. The results presented here are a small sample of the extensive measurements made by a large group of LLNL and NBS personnel under the direction Dr. Robert Donaldson and Dr. Tyler Estler respectively.

The quality of the metrology may be largely attributed to the high quality of the work environment. Figure 3 shows schematically the arrangement of closed-cycle air conditioning of the immediate surroundings of the LODTM. Figure 4 shows typical temperature variations over a period 36 hours. Temperature fluctuations are typically less than 0.01 °F.

The LODTM was tested to determine **stability, repeatability** and **accuracy**. The results shown here are just a few of the measurements made to parameterize the performance of the machine. Figure 5 shows the results of a stability test in the Z-direction, taken using a capacitance gauge over a ball. The ball was supported on a 9 inch diameter superinvar platform which was held to the surface of the spindle using a vacuum line in the center of the spindle. After approximately 80 minutes, less than one microinch of drift is evident in 4 hours. There are, however, two significant large spikes. These are the result of small variations in the vacuum supplied to the platform clamping mechanisms causing "oilcanning" of the platform. The initial instability is due to thermal equilibration after setting up the system. Such a waiting period was required in nearly all of the tests to achieve consistent results at the microinch level.

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Positioning test have been made using laser interferometers, LVDT's and capacitance gauges. Figures 6 and 7 show some of the results obtained with a capacitance gauge. Measurements were taken every 10 microinches and compared with the theoretically expected performance of the gauge. The close agreement suggests very smooth motion of the z-slide. The operation of the plane mirror laser interferometer controlling the z-slide has, however, a periodicity of approximately 6 microinches. Work by Sutton (figure 8), suggests that such an interferometer may exhibit periodic error on this scale. To measure such an error, measurements must be made on a finer mesh. Figure 9 displays the result of such a measurement made using an LVDT sensor, with individual measurements taken every microinch. A periodic error with magnitude of approximately 0.2 microinches and period of approximately 6 microinches is evident in this data. It is interesting to note that these measurements demonstrate superior performance of capacitance gauges and LVDT's in applications calling for small travel and high sensitivity.

Laser interferometers were used to measure the displacement accuracy of the LODTM. The measurements were very similar to those normally used for machine tool calibration, with the exception that the air temperature was measured at a number of points along the beam path. Figure 10 shows the displacement accuracy along the x-direction with the tool bar fully extended. The observed error consists of a scale error of 7.5 parts in 10^9 and a variation across the range of 0.75 microinches.

Straightness along the x-direction was measured using a Zerodur straightedge which had been previously calibrated at the National Bureau of Standards using standard reversal techniques. During measurements on the LODTM, the straightedge was supported at its Airey points and the calculated gravity sag removed from the data. Figure 11 shows the measured straightness of motion; figure 12 shows a later measurement after an appropriate mapping function was entered into the LODTM controller error correction tables.

Spindle measurements were made using a capacitance gauge and precision ball. Figure 13 shows a typical spindle growth curve. The two large spikes are a result of the vacuum variation induced fixture distortion mentioned above. The initial positive growth is the result of centrifugal distortion of the spindle faceplate, whereas the later negative growth results from thermal distortion of the faceplate. The growth is negative, since the distortion moves the center of the faceplate down relative to the edges which serve as the position reference for the machine. Figures 14 and 15 show typical axial spindle error motion without and with computer error compensation.

Figure 1

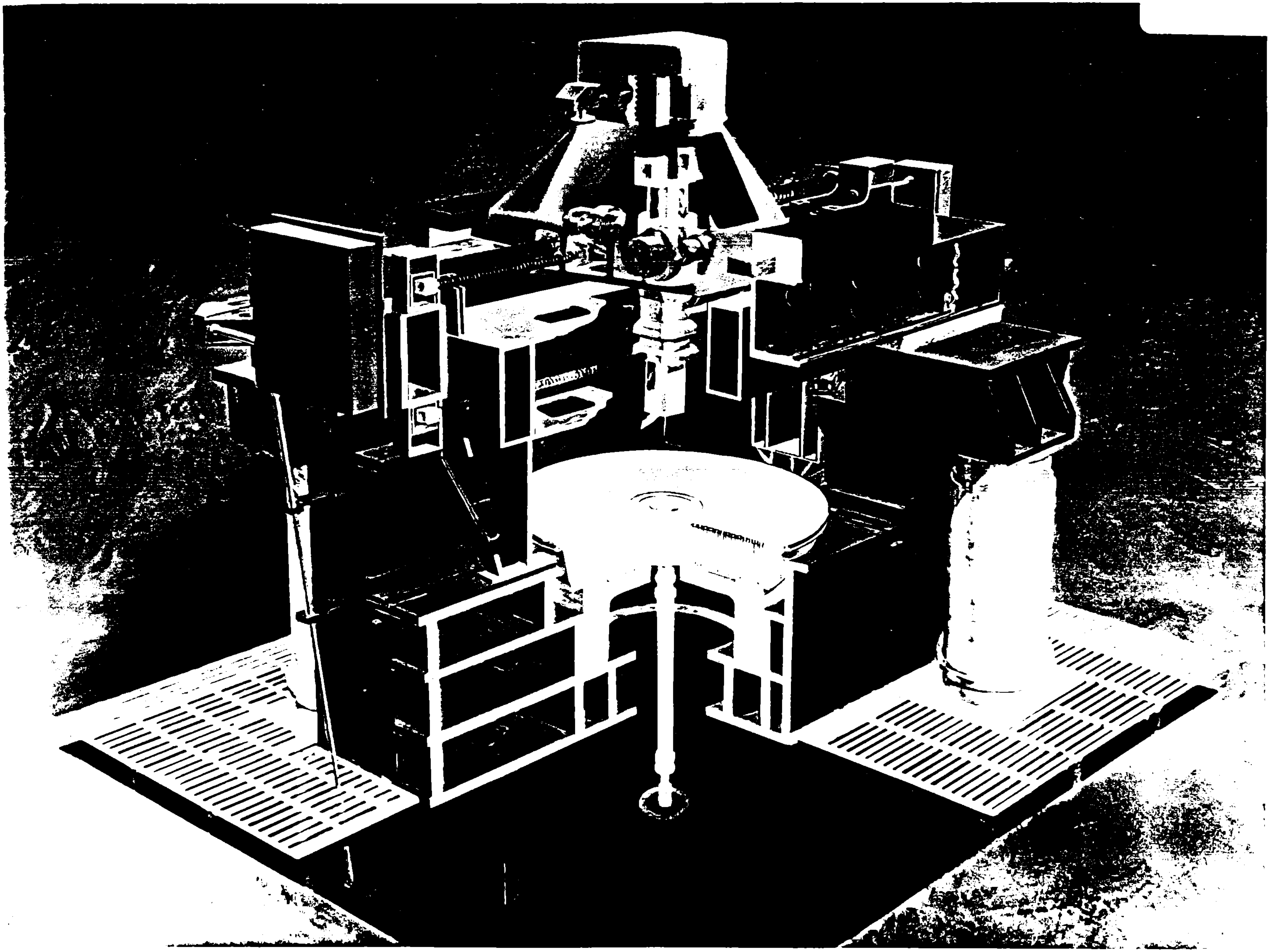
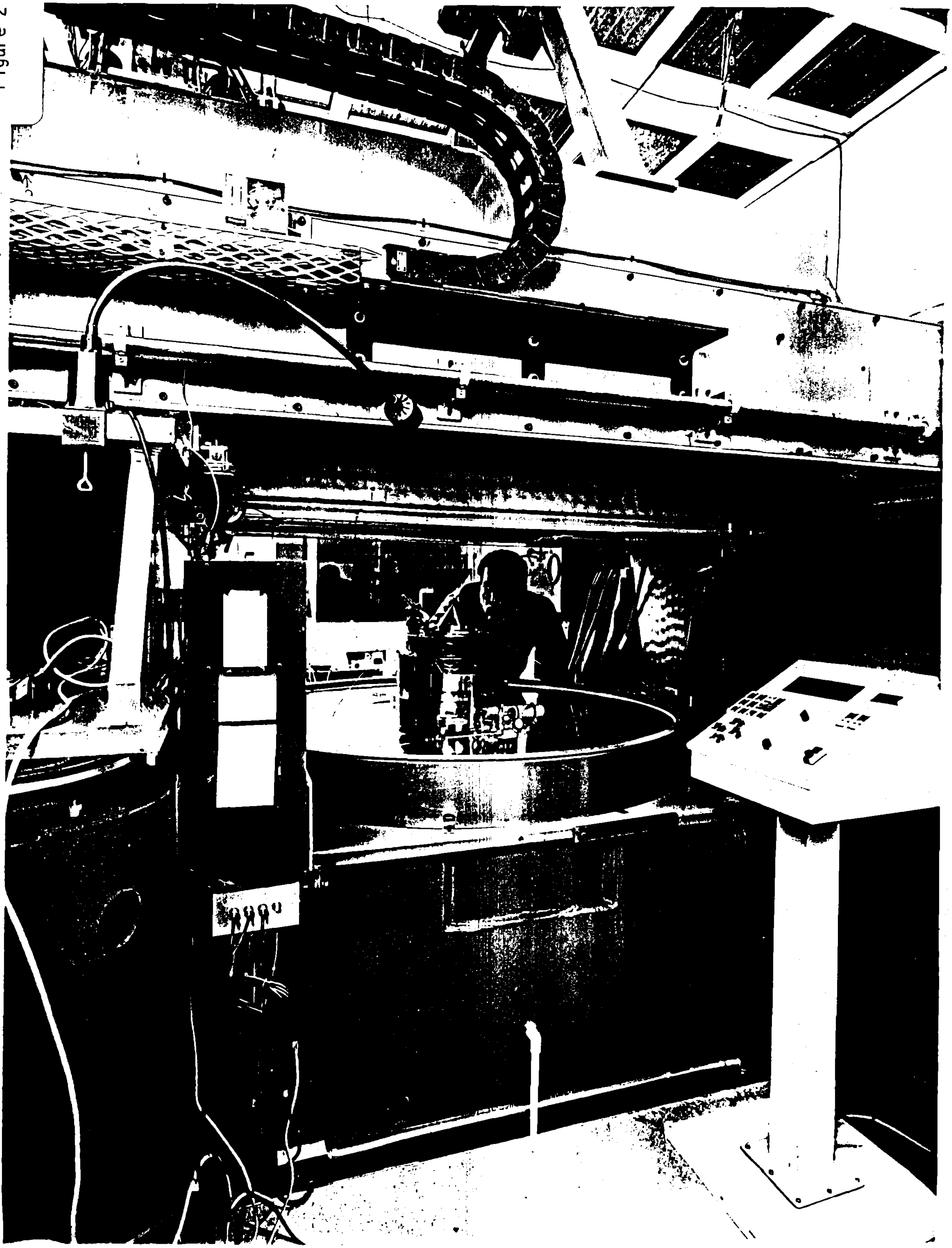
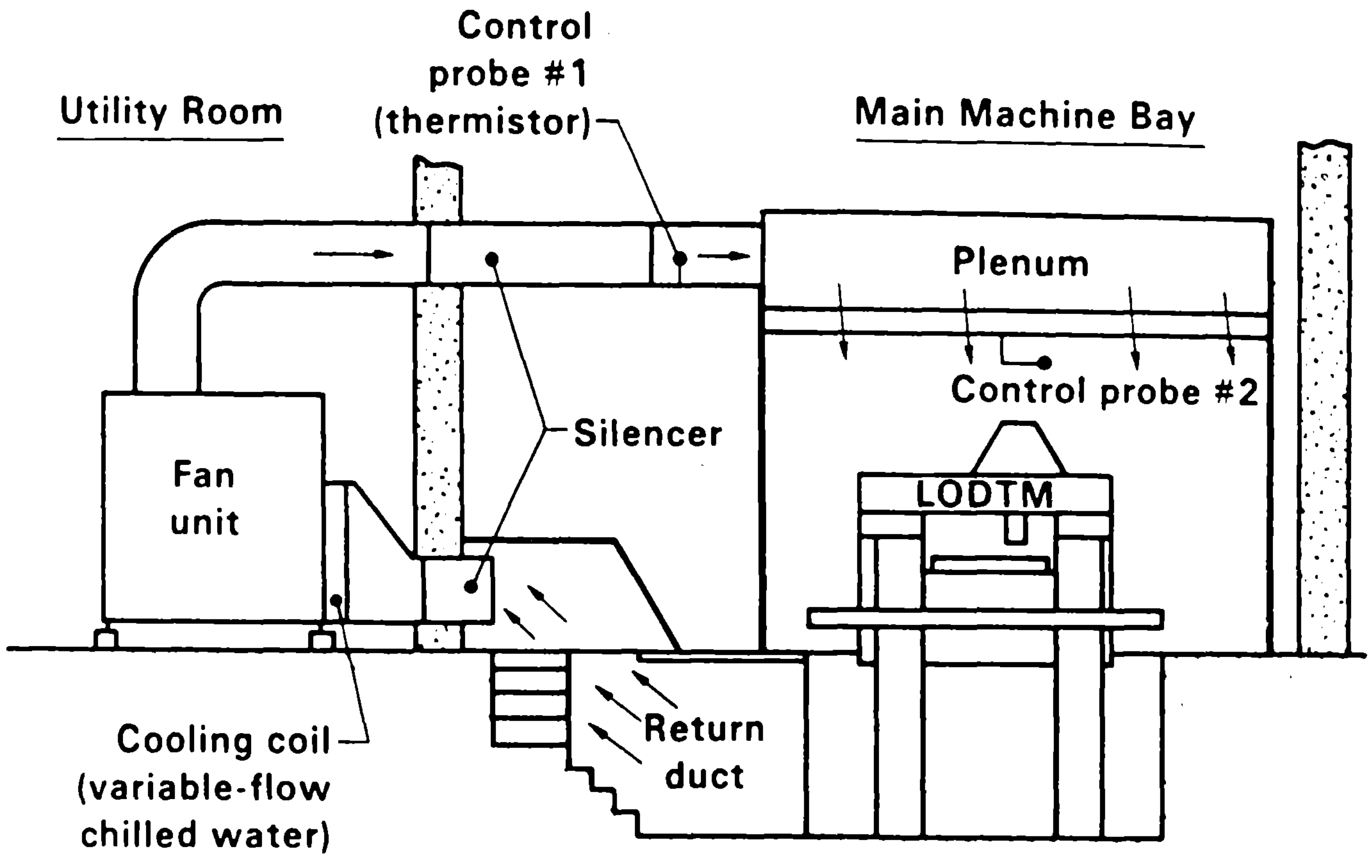
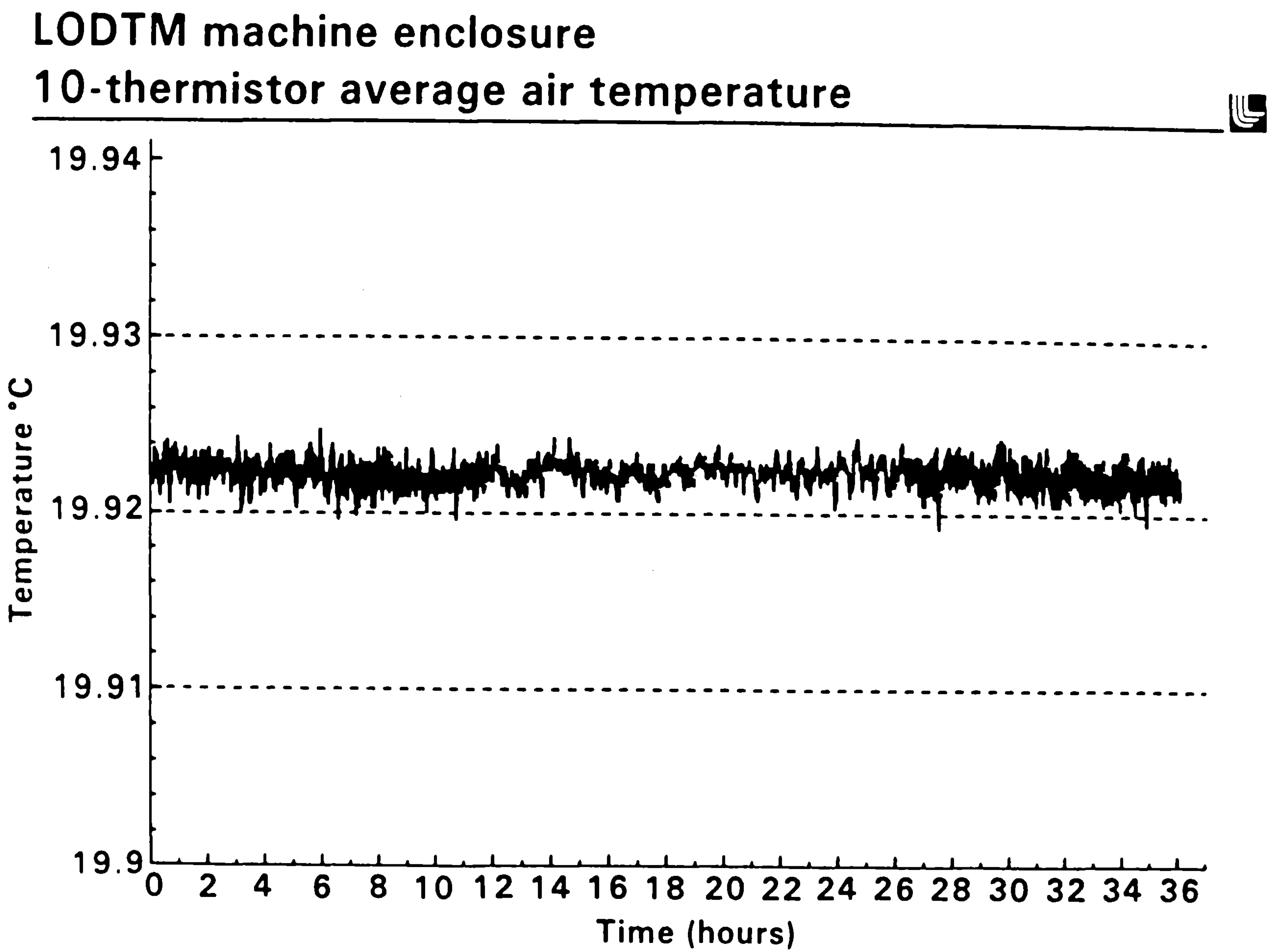


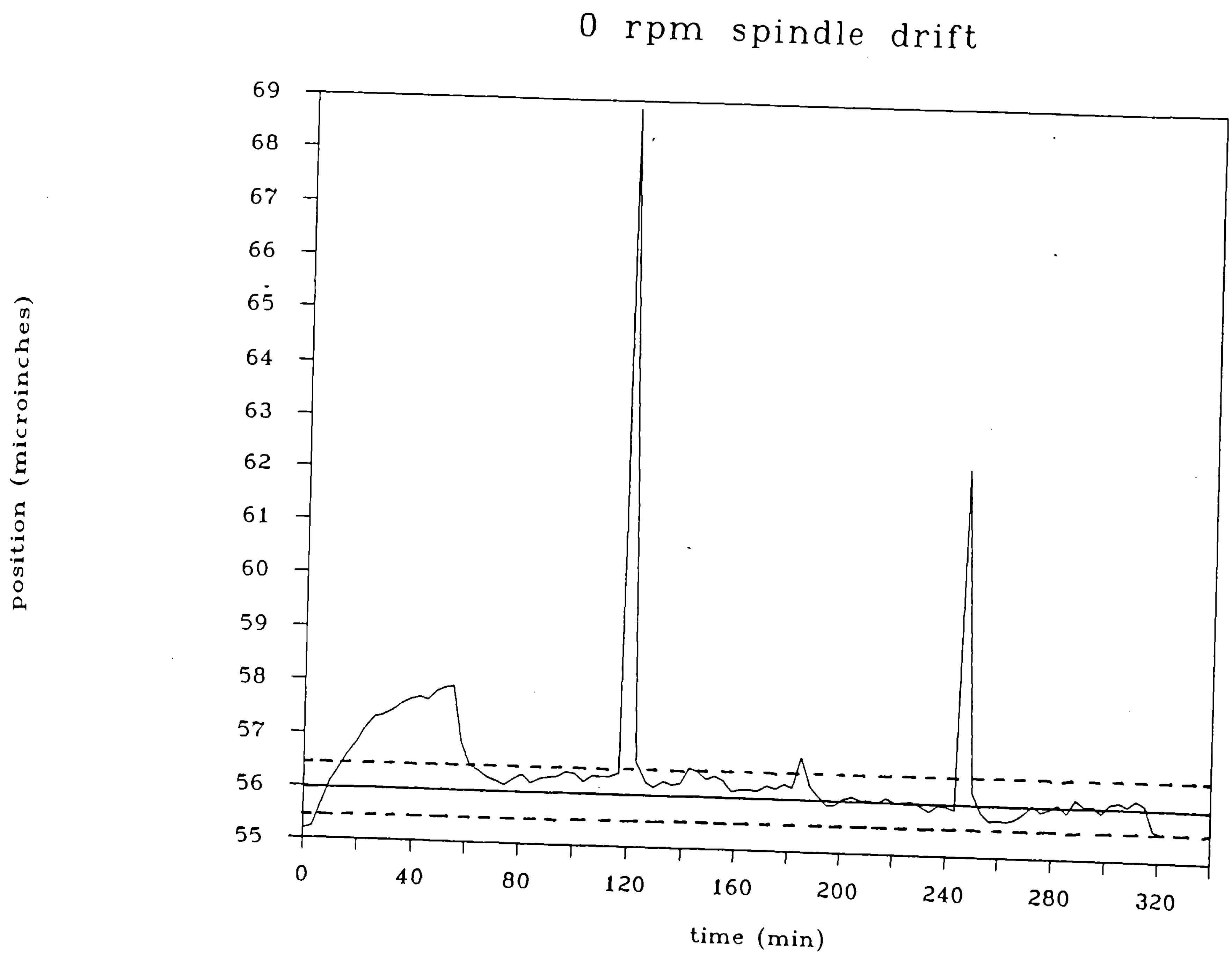
Figure 2

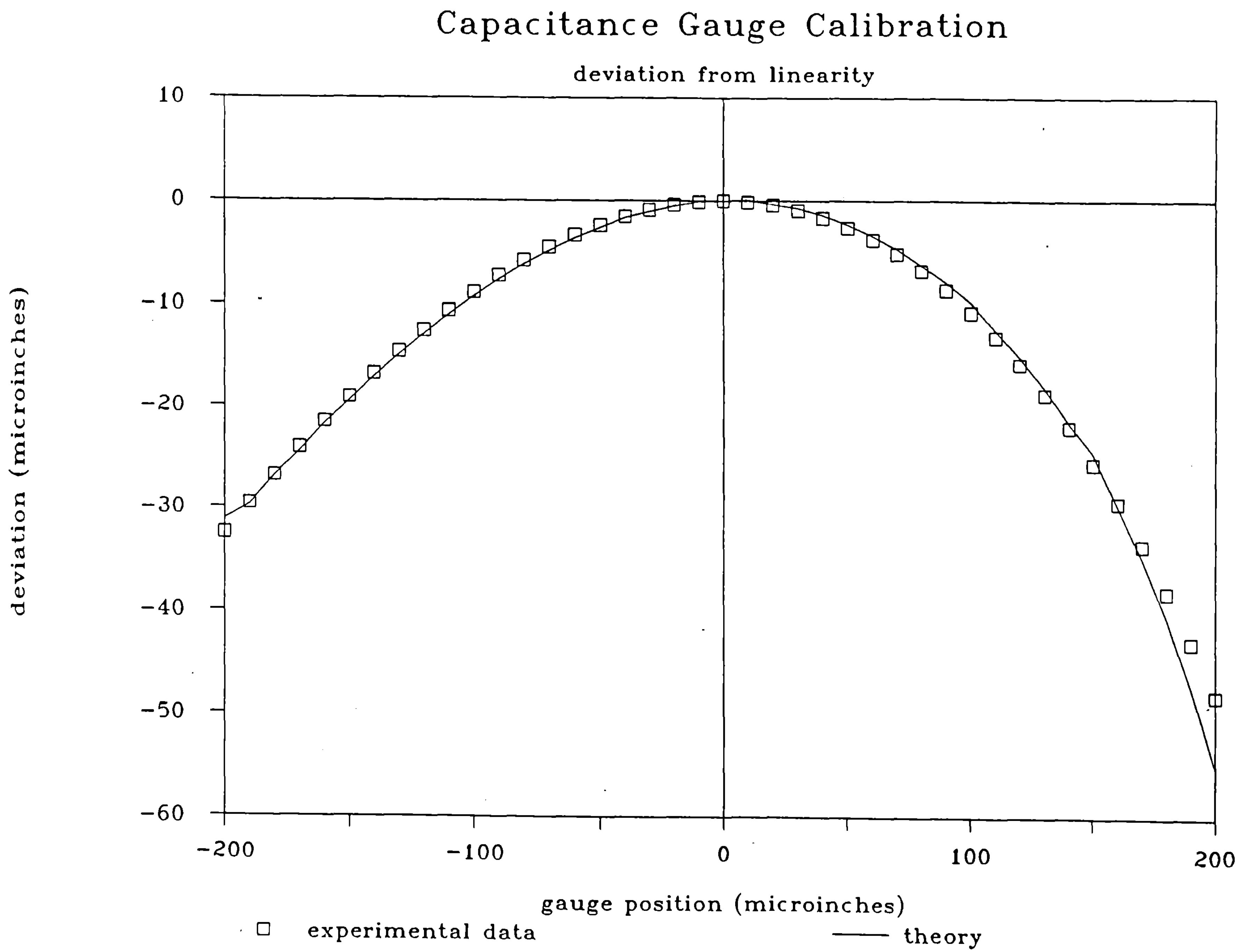


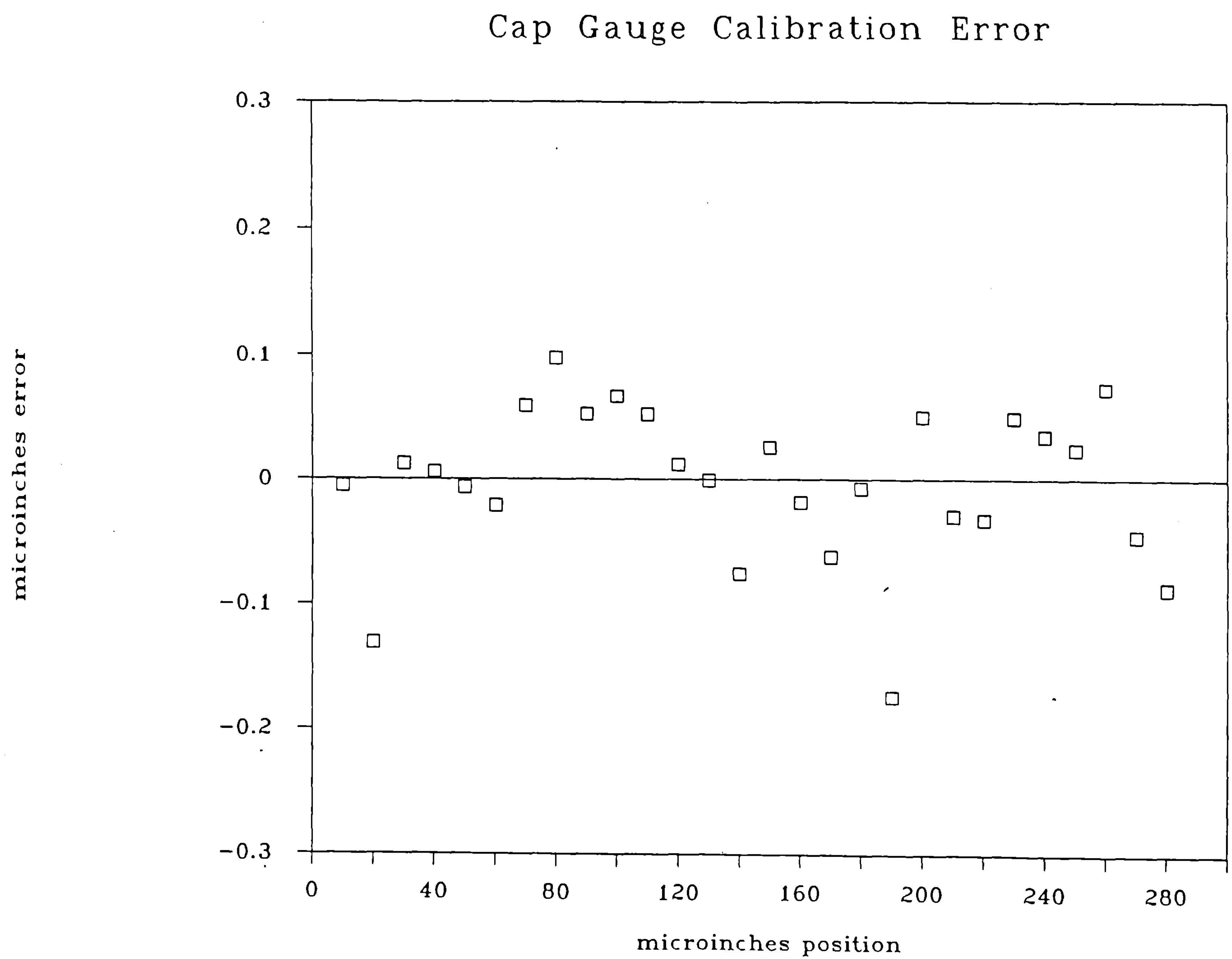
LODTM machine enclosure and air conditioning system




LODTM machine enclosure
10-thermistor average air temperature
19.94
19.93
19.92
19.91
19.9
Temperature °C
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
Time (hours)


0 rpm spindle drift
69
68
67
66
65
64
63
62
61
60
59
58
57
56
55
position (microinches)
0
40
80
120
160
200
240
280
320
time (min)


Capacitance Gauge Calibration
deviation from linearity
10
0
-10
-20
-30
-40
-50
-60
deviation (microinches)
-200
-100
0
100
200
gauge position (microinches)
experimental data
theory


Cap Gauge Calibration Error
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
microinches error
0
40
80
120
160
200
240
280
microinches position

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Rapid communications

Non-linearity in length measurement using heterodyne laser Michelson interferometry

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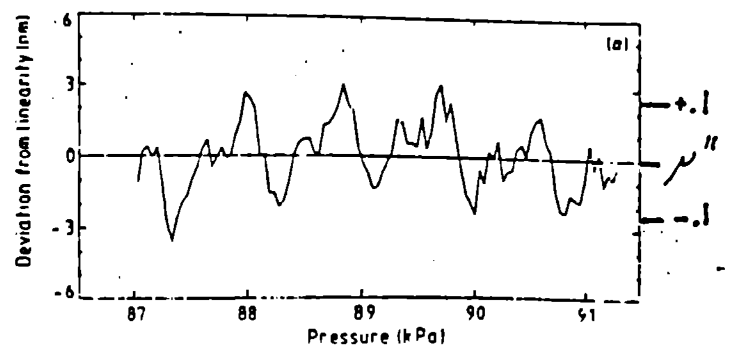


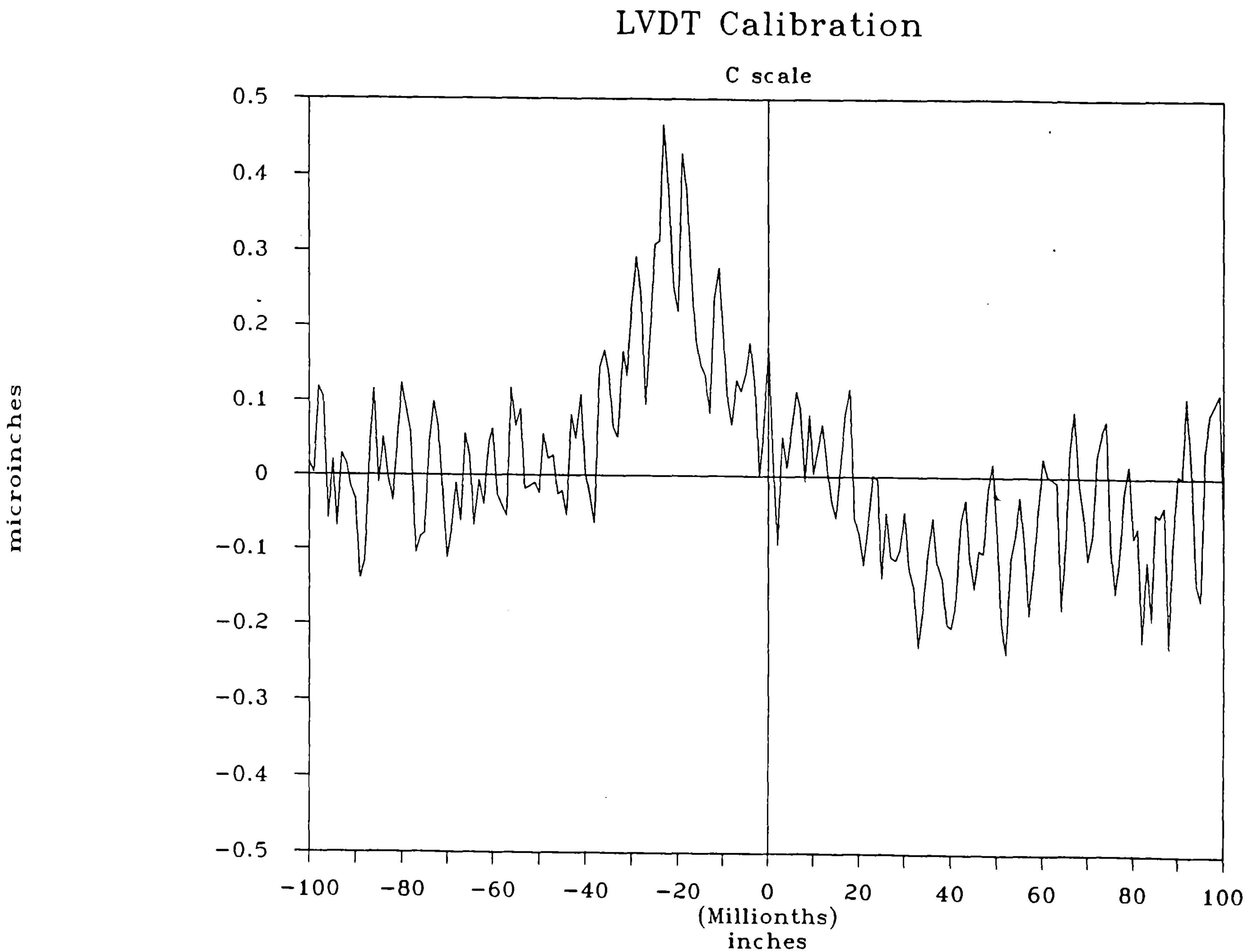
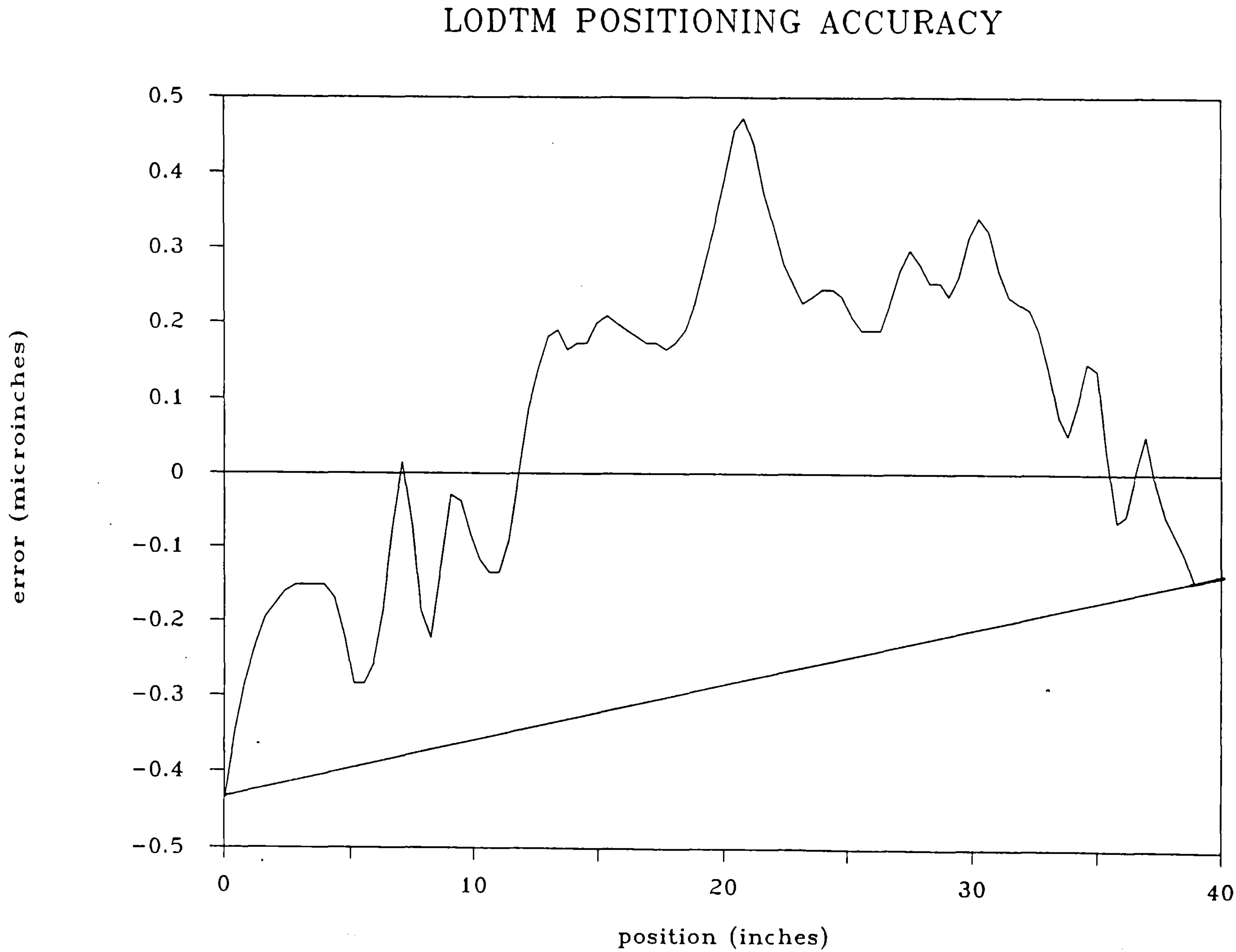

LVDT Calibration
C scale
microinches
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
−100
−80
−60
−40
−20
0
20
40
60
80
100
(Millionths)
inches

Figure 10


LODTM POSITIONING ACCURACY
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
error (microinches)
0
10
20
30
40
position (inches)

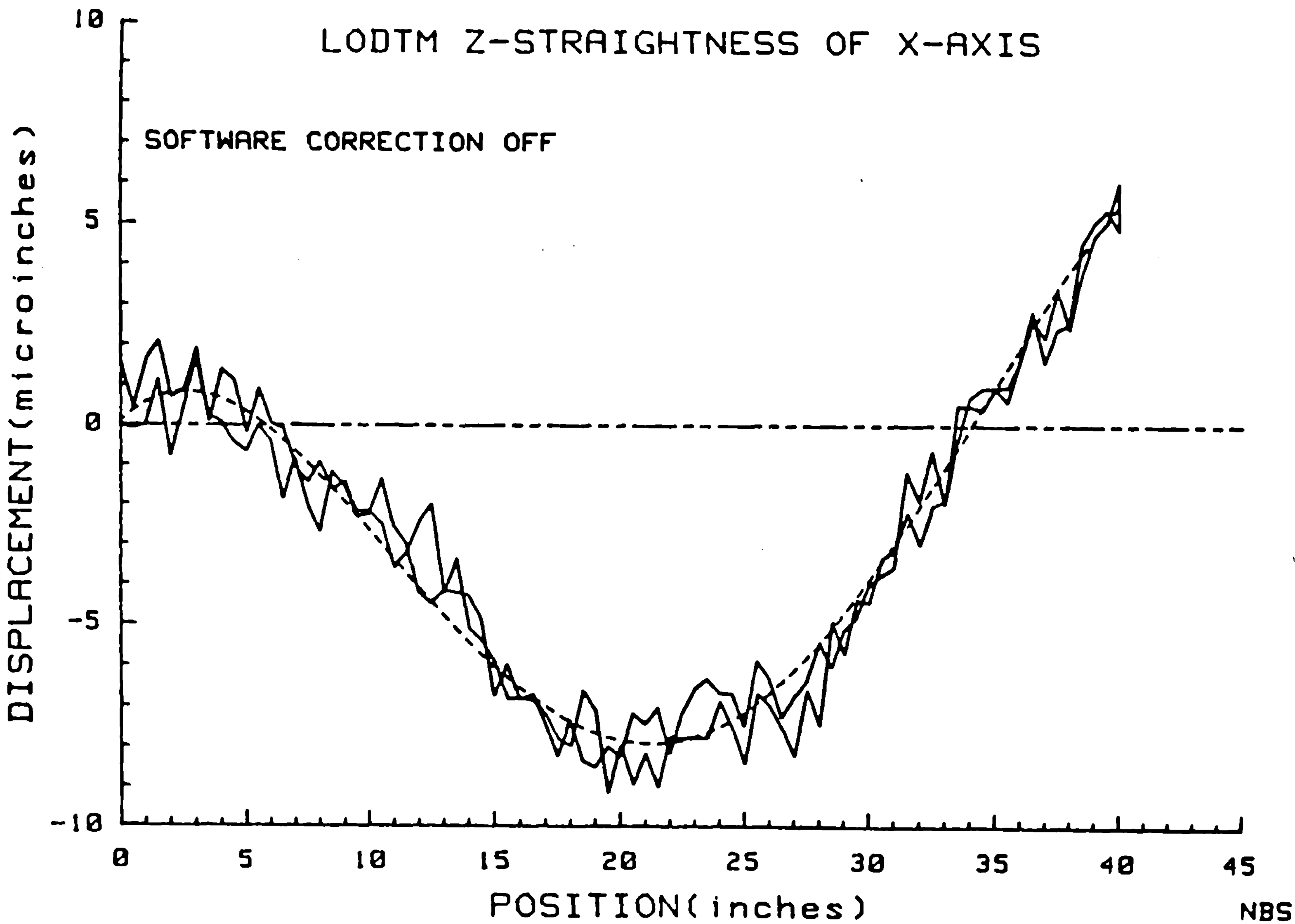
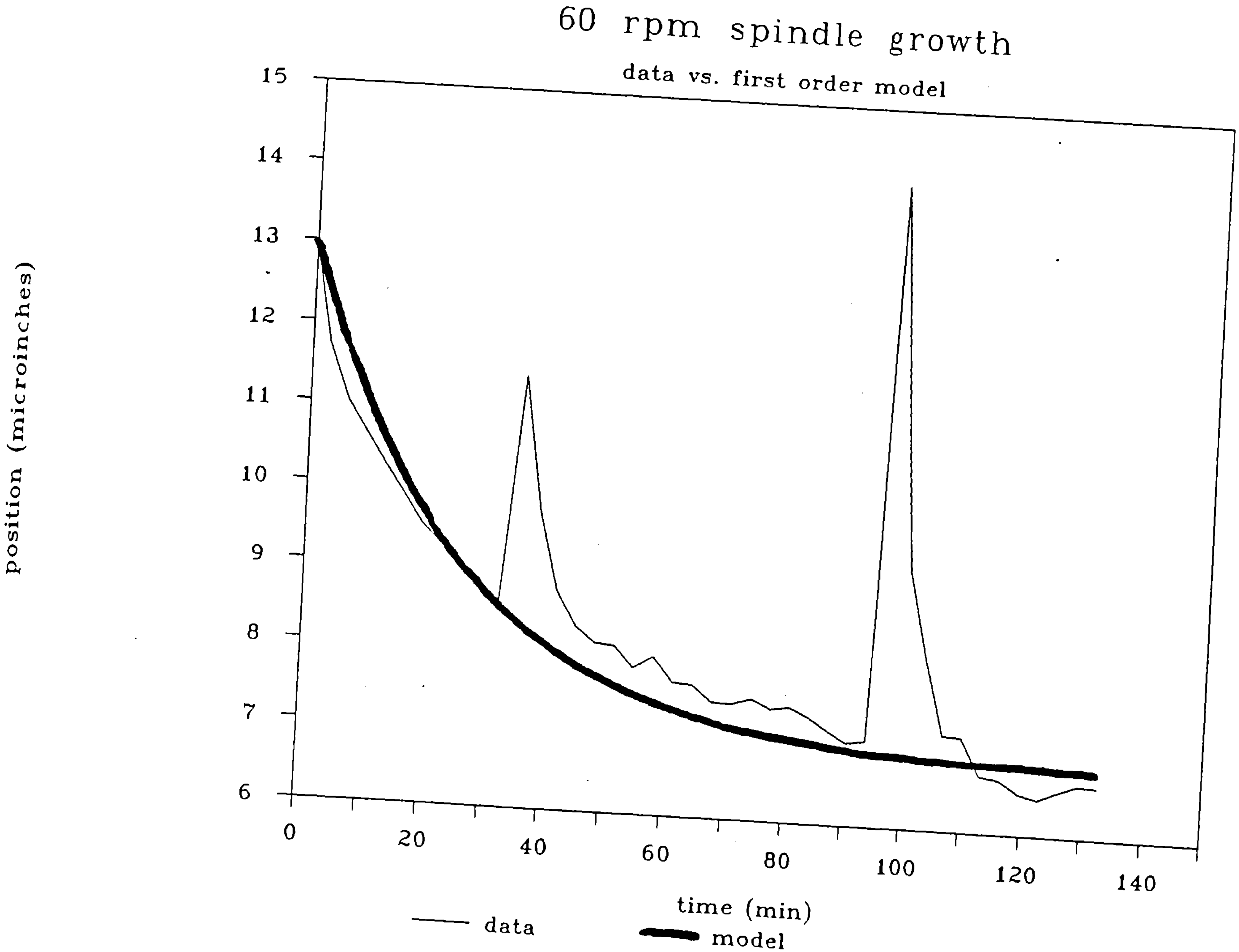

LODTM Z-STRAIGHTNESS OF X-AXIS
SOFTWARE CORRECTION OFF
DISPLACEMENT(microinches)
10
5
0
-5
-10
0
5
10
15
20
25
30
35
40
45
POSITION(inches)
NBS

Figure 12



60 rpm spindle growth
data vs. first order model
position (microinches)
15
14
13
12
11
10
9
8
7
6
0
20
40
60
80
100
120
140
time (min)
data
model

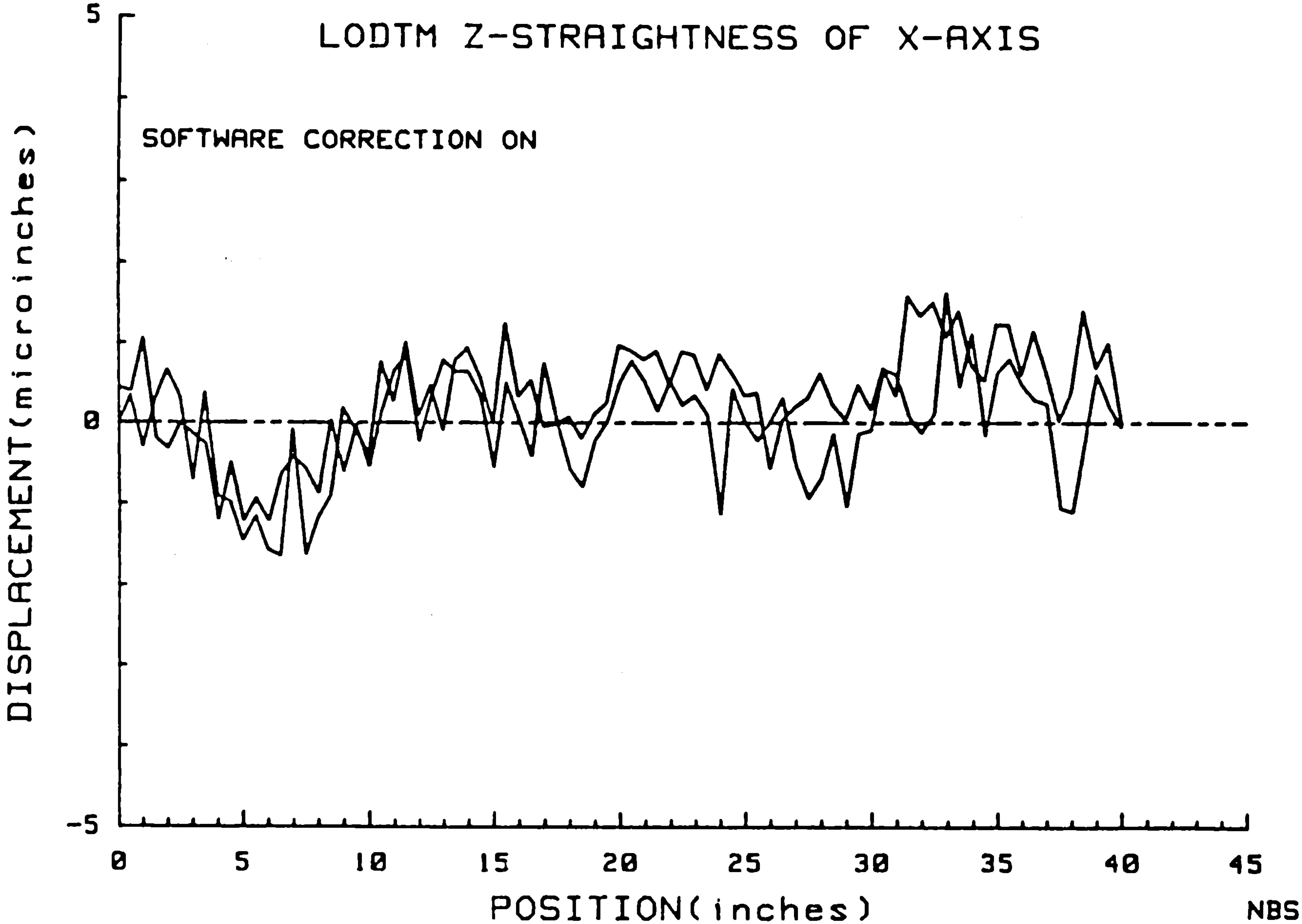

LODTM Z-STRAIGHTNESS OF X-AXIS
SOFTWARE CORRECTION ON
DISPLACEMENT(microinches)
5
0
-5
0
5
10
15
20
25
30
35
40
45
POSITION(inches)
NBS

Figure 14

040 305

5.2

LODTM Axial Spindle Motion

no correction